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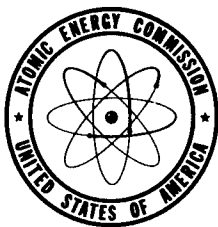
CORRELATION OF MASS TRANSFER DATA
FROM LINDE AIR PRODUCTS COMPANY ON
THE ADSORPTION OF KRYPTON ON
ACTIVATED CHARCOAL

By
J. M. Holmes

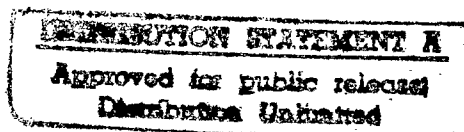
May 29, 1951

Oak Ridge National Laboratory
Oak Ridge, Tennessee

Technical Information Service, Oak Ridge, Tennessee



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CORRELATION OF MASS TRANSFER DATA FROM LINDE AIR PRODUCTS COMPANY
ON THE ADSORPTION OF KRYPTON ON ACTIVATED CHARCOAL

By
J. M. Holmes

May 29, 1951

Work performed under Contract No. W-7405-Eng-26.

OAK RIDGE NATIONAL LABORATORY
Operated By
CARBIDE AND CARBON CHEMICALS COMPANY
POST OFFICE BOX P
OAK RIDGE, TENNESSEE

TO: F. L. Culler

FROM: J. M. Holmes

SUBJECT: Correlation of Mass Transfer Data From Linde Air Products Company on the Adsorption of Krypton on Activated Charcoal.

An attempt has been made to correlate the mass transfer data from Linde's adsorption laboratory. Results of these calculations show that the data thus far give an excellent correlation using the mathematical equations presented by Hougen and Marshall, Chemical Eng. Progress 43 197(1947).

The above paper gives an equation for the fraction adsorbable vapor remaining in a gas stream from an adsorption bed as a function of time, flow rate, slope of equilibrium curve, position in bed and H_{og} , the height of a transfer unit. This equation is presented in graphical form with the following dimensionless quantities as variables:

$\frac{Y}{Y_0}$ = The fraction of the entering stream that has not been adsorbed at position x in the bed and time τ after starting operation of the bed.

$$b\tau = \frac{cG}{\rho H_{og}} \times \tau$$

where:

c = slope of equilibrium curve gm charcoal / gm carrier gas.

G = Mass flow rate $\frac{\text{gm}}{\text{hr cm}^2}$

ρ = Bulk density of charcoal gm/cc

H_{og} = Height of a transfer unit = cm

τ = Time from start of gas flow, hr.

ax = Number of transfer units = $\frac{x}{H_{og}}$

where:

x = length of bed, cm.

The data from Linde Air Products Company were taken in the following manner. Nitrogen containing 1.5% Krypton was bled through a bed of charcoal at -183°C . until the concentration of the exit gas showed 100 parts per million of krypton by mass spectrometer analysis. The adsorbed nitrogen and krypton were then stripped from the bed and analyzed. A material balance of the system showed that the data checked quite well except for the lowest flow rate of 180 cc/min. This flow rate is recalculated to check the material balance and becomes 118.4 cc/min for this work.

The Linde data also include a static equilibrium determination of the adsorption of krypton on charcoal. The application of the Freundlich theory to these data give the following formula which fits the data quite well:

$$v = 256p^{0.110} \quad (-183^{\circ}\text{C})$$

where:

v = adsorbate cc/gm

p = pressure over bed in m.m. H_g

The correlation method is as follows:

According to the Hougen and Marshall equation, for $y/y_0 = 0.00667$ which is the concentration for this case, the value of ax (number of transfer units) becomes approximately 5.40 at $bx=0$. The Linde data of time vs. flow rate were then extrapolated on semi log paper (Figure 2) to zero time. The flow rate at which the exit concentration would be 100 p.p.m. at zero time is therefore 420 cc/min. Using the value of 5.4 transfer units, the height of a transfer unit at 420 cc/min becomes 2.036 cm. From this one point and the theory that the H_{og} varies as the 0.51 power of G , the value of H_{og} for any flow rate G , may be calculated.

The above theory was checked by actually calculating H_{og} 's from individual values given in the data. However, Hougen and Marshall assumed a linear equilibrium line for their derivation. For this case, the equilibrium line is far from linear as is shown by the 0.110 exponent in the equilibrium equation. For this calculation, the log mean value of the equilibrium line slope for entrance and exit conditions was used. Next,

for each value of G and τ , the values of bx and ax were calculated leaving the value of H_{og} as an unknown. H_{og} was then eliminated by using the ratio ax/bx . Hogen and Marshall's curves were extrapolated to a value of 0.00667 (Figure 3) and from this curve, another curve was constructed as ax/bx vs. ax for the constant $y/y_o = 0.00667$ (Figure 4).

From this last curve it was possible to find H_{og} from the determined values of ax/bx . This was done and the calculated values gave excellent agreement (within 16%) with the original method of determining H_{og} (Figure 5).

The above correlation should therefore apply to any bed, at any flow rate, for a temperature of -183°C . and the same grade of activated charcoal (Columbia Grade CXA).

J. M. Holmes

FOSTER WHEELER CORPORATION

CALCULATION OF H_{og} FROM LINDE DATA

A. Velocity when $Br = 0$, $= \frac{420 \text{ cc}}{2.1 \text{ min}} = 200 \frac{\text{cm}}{\text{min}}$

No. of transfer Units ≈ 5.4 (From Extrapolation)

Height transfer Unit $= \frac{11.0}{5.4} = 2.036 \text{ cm.}$

$\ln H_{og} = 0.710$ $\ln V = 5.30$

Theory gives $\frac{\ln H_{og(1)}}{\ln H_{og(2)}} = 0.51 \frac{\ln G(1)}{\ln G(2)}$

$\ln H_{og(1)} = \ln H_{og(2)} \times \frac{\ln V(1)}{\ln V(2)} \times 0.51$

(V proportional to G for standard conditions and N_2 carrier gas).

B. Calculation of G:

Dimensions of Bed

Volume = 23.1 c.c.

Height = 11 cm.

Area = 2.1 cm^2

Diameter = 1.64 cm.

Density of Carbon = $\frac{10 \text{ gm}}{23.1 \text{ cc}} = 0.433 \text{ gm/cc.}$

C. True flow from material balance for observed flow of 180 cc/min.

$\frac{2930 \text{ cc Kr}}{27.5 \times 60 \text{ min}} \times \frac{1}{0.015} = 118.4 \text{ cc/min}$

D. Mass Flow Rate (At Standard Conditions)

$$G = \text{Flow} \frac{\text{cc}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{1}{2.1 \text{ cm}^2} \times \frac{\text{mole}}{22,400 \text{ cc}} \times 28 \frac{\text{gms}}{\text{mole}}$$

$$= 0.0358 \times \text{Flow} \frac{\text{cc}}{\text{min}}$$

<u>Flow</u> <u>cc/min</u>	<u>G</u> $\frac{\text{gms}}{\text{hr cm}^2}$	<u>Velocity through Empty</u> <u>Tube cm/min</u>
118.4	4.23	56.4
230	8.22	109.5
270	9.64	128.6
320	11.42	152.4

E. Equilibrium Constant C

C = Slope Equilibrium Line

$$= \frac{\text{gm Kr/gm Gas}}{\text{gm Kr/gm charcoal}}$$

$$= \frac{83.7 \times \text{Press. Kr(m.m.)}}{28 \times 760} = 1.053 \frac{p}{v}$$

$$\frac{v}{267.6} (\text{cc/gm})$$

F. Formula for Kr on Charcoal at -183°C .

$$v = 256P^{0.110}$$

Partial Press. Kr. entering

$$= 0.015 \times 760 = 11.4 \text{ mm}$$

$$v = 256(11.4)^{0.110} = 334 \text{ cc/gm.}$$

Partial Press. Kr. leaving at end of run.

$$= 100 \times 10^{-6} \times 760 = 0.076 \text{ mm}$$

$$v = 256(0.076)^{0.110} = 193 \text{ cc/gm}$$

- 7 -

$$C_1 = 1.053 \times \frac{11.4}{334} = 0.03594$$

$$C_2 = 1.053 \times \frac{0.076}{193} = 0.000415$$

$$\log \text{ mean } C = \frac{0.03594}{2} - \frac{0.000415}{2} = 0.00796$$

$$\ln \frac{0.03594}{0.000415}$$

G. Calculation of br'

$$\begin{aligned} br &= \frac{CG}{P \times H_{og}} \times \text{time} \\ &= \frac{0.00796 \text{ G } \tau}{0.433 \times H_{og}} = 0.0184 \frac{\text{G } \tau}{H_{og}} \end{aligned}$$

$$\frac{ax}{br} = \frac{11/H_{og}}{\tau \times 0.0184 \text{ G}/H_{og}} = \frac{598}{\text{G } \times \tau}$$

H. Determination of H_{og}

Flow	G	Time	ax/bx	ax	H_{og}
118.4	4.23	27.5	5.14	8.90	1.24
230	8.22	11.0	6.62	7.80	1.41
270	9.64	8.5	7.30	7.40	1.49
320	11.42	5.25	9.98	6.26	1.76

I. Check of H_{og} with Calculated Value

When $Bx = 0$

$H_{og} = 2.036$

$V = 200$

$H_{og} = 2.036$ $\frac{V}{200}^{0.51}$ (V proportional to G for standard conditions and N_2 carrier gas).

Flow	Velocity	Extrapolated H_{og}	H_{og} Determined	% Deviation
118.4	56.4	1.07	1.24	16%
230	109.5	1.50	1.41	6%
270	128.6	1.62	1.49	8%
320	152.4	1.77	1.76	1%

Adsorption Mass Transfer Data - Linde Air Products Company

From Report 5/4/51

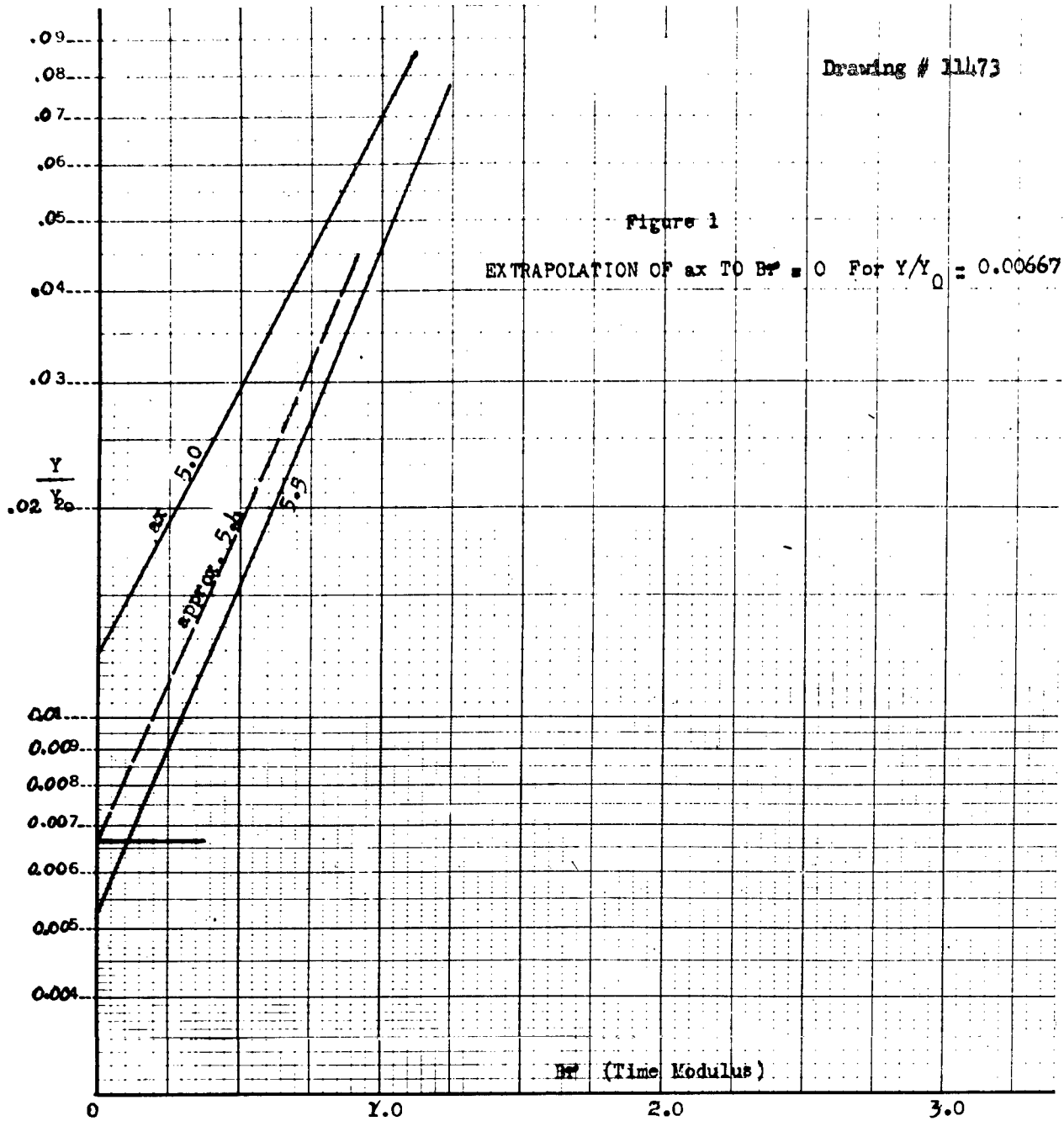
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TABLE I

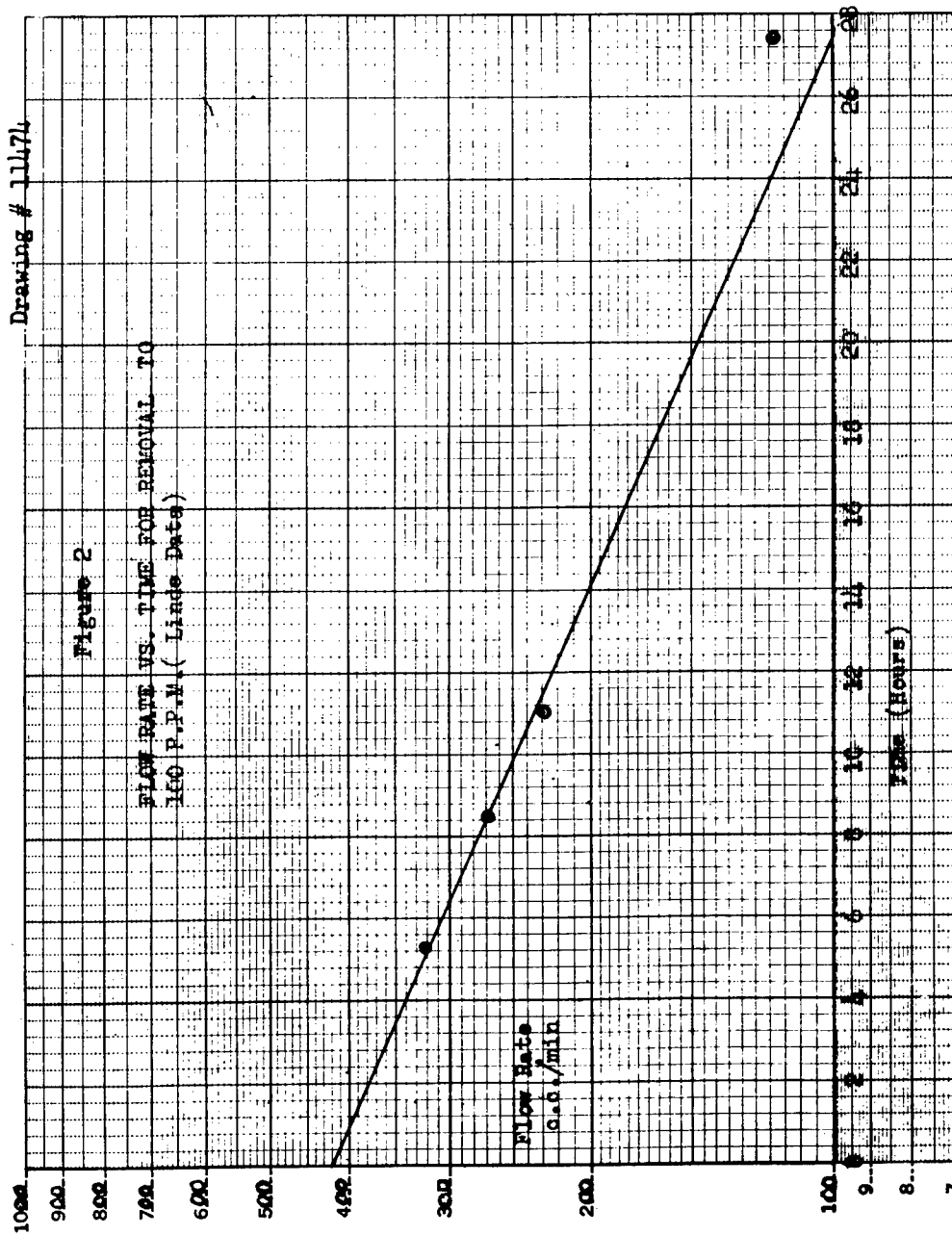
<u>Input Flow</u>	<u>Time to reach 0.01% Krypton in exit gas</u>	<u>Volume of desorbed gas from trap.</u>	<u>Mass spec- trometer Analysis of Desorbed Gas</u>	<u>Capacity of trap for Total Gas</u>	<u>Linear Velo- city of sample thru empty trap</u>	<u>Time of Contact</u>
180 cc/min.	27-1/2 hrs.	3660 cc.	80% Kr. 20% N ₂	366 cc/gr.	1.43 cm/sec.	7.7 sec.
230 "	11 "	3610 cc.	62.5% Kr. 37.5% N ₂	360 "	1.82 "	6.0 "
270 "	8-1/2 "	3685 cc.	66% Kr. 34% N ₂	369 "	2.15 "	5.1 "
320 "	5-1/4 "	Not measured	-----	----	2.55 "	4.3 "

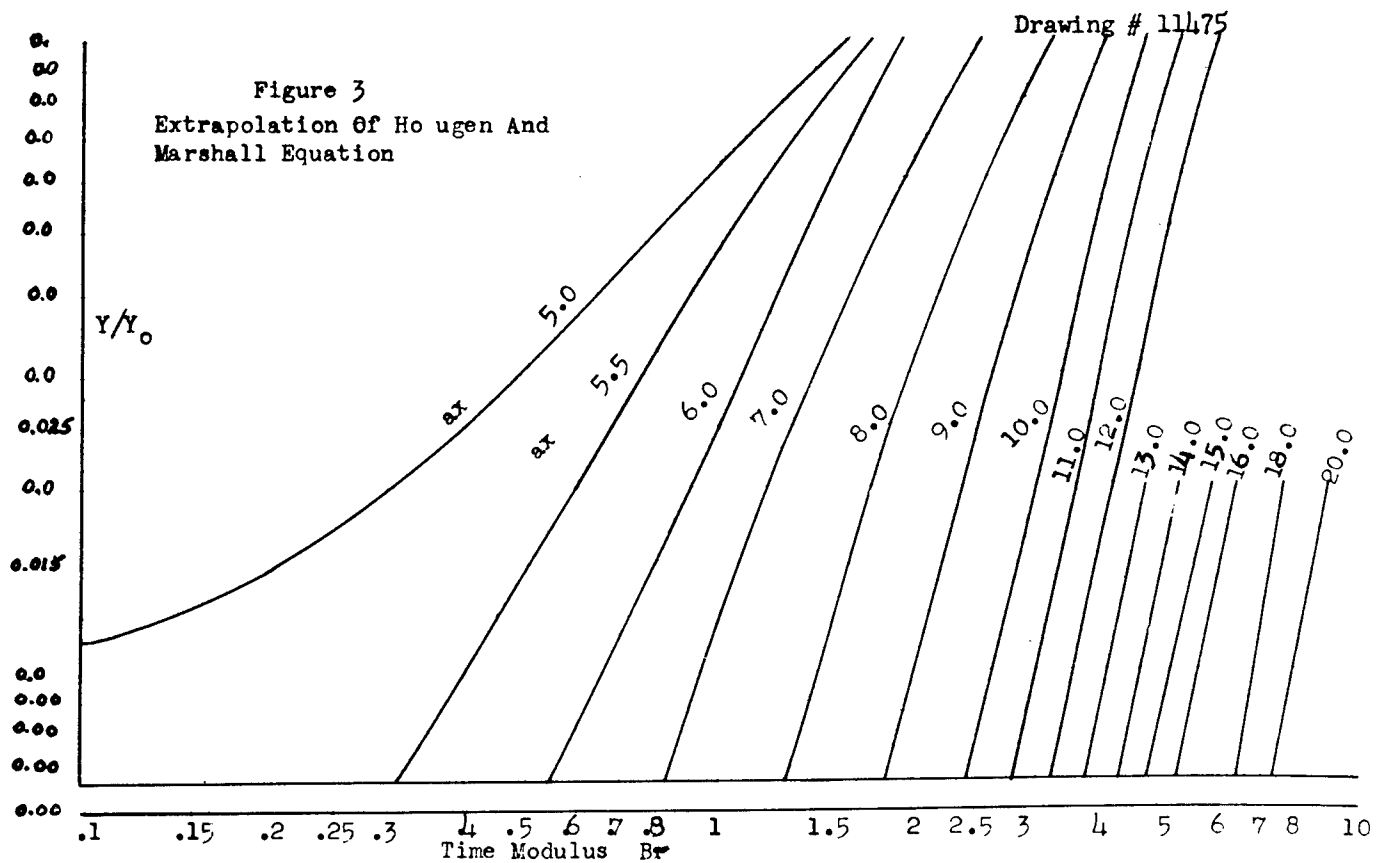
TABLE II

<u>Input Flow</u>	<u>Time to reach 0.01% Kr. in Exit Gas</u>	<u>Volume of Kr. thru Inlet meter</u>	<u>Volume of Kr. in Desorbed trap</u>
180 cc/min (118 corrected)	27-1/2 hrs.	4450 cc.	2930 cc.
230 cc/min	11 "	2277 cc.	2275 cc.
270 "	8-1/2 "	2066 cc.	2430 cc.
320 "	5-1/4 "	1515 cc.	-----



Drawing # 111474





Data For $Y/Y_0 = 0.00667$

ax	Br	ax/Br
5.5	.318	17.30
6.0	.550	10.91
7.0	.820	8.54
8.0	1.28	6.25
9.0	1.82	4.95
10.0	2.42	4.13
11.0	2.85	3.86
12.0	3.30	3.64
13.0	3.70	3.51
14.0	4.20	3.33
15.0	4.60	3.26
20.0	7.24	2.76
40.0	20.0	2.00
60.0	36.5	1.64
80.0	50.0	1.60
100.0	64.5	1.55

Drawing # 11477

